Vol. VI. DECEMBER, 1889. No. 8.

AMERICAN METEOROLOGICAL JOURNAL.

A Monthly Review of Meteorology and Medical Climatology.

TABLE OF CONTENTS.

ORIGINAL ARTICLES: PAGE

Ferrel's Convectional Theory of Tornadoes. WILLIAM MORRIS DAVIS and CHARLES EMERSON CURRY 337

State Tornado Charts. LIEUT. J. P. FINLEY. Indiana 350

Theory of Storms, Based on Redfield's Laws. H. FAYE, Membre de l' Institut, etc. 355

Meteorology at the Paris Exposition. A. LAWRENCE ROTCH 362

Distribution of Average Wind Velocities in the United States. (Concluded.) DR. FRANK WALDO 368

CORRESPONDENCE:

Thermometer Errors. W. A. ROGERS 382

CURRENT NOTE:

Atlas of Clouds 383

ANN ARBOR, MICH., U. S. A.:

METEOROLOGICAL JOURNAL COMPANY.

19, 21 and 23 Huron Street.

Single Copies, 25 cents. Per Annum, $2.00. In European Countries, $2.25.

Entered at the Ann Arbor Postoffice as Second Class Matter.

The following Important Book is now Ready.

SEAS AND SKIES IN MANY LATITUDES

OR

WANDERINGS IN SEARCH OF WEATHER.

By the Hon. RALPH ABERCROMBY, F. R. Met. Soc.,
Author of "Principles of Forecasting," "Weather," in the International Scientific Series, Etc.

Demy 8vo, cloth extra, with 3 Maps, 9 Photographs, and 33 Woodcuts by Pritchett, Whymper, Cooper, Etc. *Price*, $4.50.

In this book the author describes his travels in Egypt, Australia, Fiji, India, Borneo, Japan, the United States and the White Sea, Etc., with special reference to the aspect of the sky and the weather from day to day.

Beaten tracks are only noticed sufficiently to bind the narrative together; but less known places, such as the cannibal Islands of Fiji, the edible birds' nest caves of Borneo, and the rich Russian monastery of Solivetzki in the White Sea are fully described and illustrated.

The author in the first chapter gives his impressions of the climate of Canada; and his observations on the influence of battles on weather, made during the war, in front of Petersburg, Virginia.

The last two chapters are devoted to an account of the mountain observatory on Pike's Peak, and to a popular account of the forecasting work, as carried on in the U. S. Signal office three years ago.

London: EDWARD STANFORD, 26 and 27 Cockspur Street, Charing Cross, S. W.

MAILED FREE ON RECEIPT OF POST ORDER FOR $4.50.

By the same Author and from the same Publisher.

INSTRUCTIONS FOR OBSERVING CLOUDS ON LAND AND SEA.

Twenty-two pages. Photo-plate of ten typical cloud forms, and six woodcuts. Mailed free on receipt of 40 cents.

This little book gives clear instructions for naming the leading varieties of clouds; and for determining both the direction of their motion and the direction in which the linear forms of cirrus trend.

The illustrations are taken from all parts of the world, and the instructions are available for any country.

"The instructions for observing clouds which he (Mr. Abercromby) now issues, are undoubtedly an advance over those at present in use.—American Meteorological Journal.

THE AMERICAN
METEOROLOGICAL JOURNAL.

VOL. VI. ANN ARBOR, DECEMBER, 1889. No. 8.

ORIGINAL ARTICLES.

FERREL'S CONVECTIONAL THEORY OF TORNADOES.

BY WILLIAM MORRIS DAVIS AND CHARLES EMERSON CURRY.*

1. *General Facts Concerning Tornadoes.*—The facts that are now generally understood in regard to tornadoes in this country are that they are ascensional whirling storms of small area but of great violence; that they are accompanied by a whirling funnel-cloud, pendant from a great thunder-storm cloud mass above; that their whirling is from right to left; and that they advance at a rapid rate generally to the northeast. It is recognized that they are commoner in warm or hot and moist than in cool and dry weather, and that they are associated in a rather definite way with the southeastern quadrant of cyclonic storms. It is also understood that waterspouts are tornadoes occurring over water.

2. *General Method of Investigation.*—From these general facts and from a flood of details concerning individual tornadoes, the mind naturally advances to seek the cause of phenomena so extraordinary; and in this search the principles now accepted in scientific investigation should be taken as guides. The facts are matters of observation, acquired in the first step

*An essay by instructor and student in a second course in Physical Geography in Harvard College, 1887–89.

of the investigation, in whose record there is no necessity for thought or reflection, except so far as is required for care and accuracy. Then with the facts in mind, the eyes may be for a time closed and thought awakened; ingenuity is summoned to devise some means of connecting the observed facts with previously acquired knowledge, and the imagination is set to work to frame hypotheses, to picture the ideal processes that may singly or together account for the facts in accordance with the rational results of previous study. This is "theorizing," against which some students have an unwarrantable prejudice; for it is an absolutely essential part of investigation. If the suggested hypotheses are confounded with the facts, or if they are accepted as established on weak or insufficient evidence, or if the mere making of an hypothetical suggestion so warps the mind that it is blinded to new facts and prejudiced against other suggestions, then theorizing may indeed work harm: but any harm that comes in this way is the fault of the investigator and should not be charged against the logical method of investigation. It is not enough that an hypothesis, which has been suggested to account for the observed facts, should be loosely conceived. It must be deductively followed out as far as possible to all its consequences; this also being an internal mental process, quite apart from immediate observation, but calling for a good knowledge of related facts and principles, so that the deductive extension of the hypothesis may be truthful.

Then comes the third step in the investigation, by which the hypotheses suggested in the second step to account for the facts of the first step are tested as to their sufficiency. It is not enough that an hypothesis should account in a general way for the facts that it was invented to account for. Of course it must do that; but it must do more also. It must in some additional way so far recommend itself that we become persuaded that it not only may account for the facts, but that it truly represents the process by which the facts are actually produced. The verification or testing of an hypothesis therefore requires much critical discrimination. Among the best tests that can be applied are: strict quantitative correspondence between the

hypothetical process and the observed facts; or the bringing to light of unperceived correlations; or the ability to explain subsequently detected facts; or even the prediction of the occurrance of facts before unnoticed. Conversely, with the affirmative verification of one hypothesis, which may then take rank as a accepted theory, there should go the exclusion of all insufficient hypotheses: but it is well to remember that many processes may be at work in apparently simple phenomena; there may be several successful hypotheses.

When investigation reaches this safe haven, and when its results are well seasoned by several years of general discussion and approval, they are worthy of general acceptance. It must always be borne in mind that theory does not alter fact, and that even if clearly and emphatically stated, an explanation has not the same order of verity as a good observation: but explanation must accompany observation and theory must follow fact, if we would advance our science.

3. *Outline of this Essay.*—There has been much written on tornadoes and the theory of their action in recent years that has seemed to us open to criticism in two ways: in the first place the essentials of the method of investigation above outlined are too little regarded; and in the second place, a very competent and well reasoned theory of tornadoes is by many writers passed by unmentioned as if unknown. Professor Ferrel has, in his various essays, developed a theory of tornadoes that has no competitor in its careful foundation on facts, in its admirable physical and mathematical discussion, and in its many points of verification. It has therefore seemed to us worth while to make a general statement of his theory and at the same time to bring together in a brief way a number of references to other essays on the subject, in the hope that the readers of the JOURNAL might therein find matter of value, and that the observation of several points not yet well made out in the action of tornadoes might receive increased attention.

On the basis of the generally accepted facts concerning tornadoes, and in the light of what is generally accepted concerning the physical processes of meteorology, Ferrel first infers the

association of tornadoes with convectional currents; he then inquires into the condition of occurrence of such currents and proceeds to deduce the result of their action in such circumstances of special development as the known facts about tornadoes indicate; he then compares his deductions with the natural occurrences, as to quality and quantity, and re-examines the whole question to see if the understanding and correlation of facts, not before perceived or comprehended, are now made more clear: and on completing such a review, he and those who follow him will be in position to judge of the sufficiency of the hypothesis put forward, and of its worthiness to be regarded as an acceptable theory.

4. *Insufficient Hypotheses.*—It will be well to dismiss certain insufficient hypotheses before taking up the main line of discussion. A number of writers have attributed tornadoes to electricity, sun-spots, lunar action, etc.;* but these hypotheses are at present merely gratuitous suggestions; they may some day develop further, and this day may be hastened by more critical work on the part of their authors; but in the form that they have been advanced they deserve little attention. What if one tornado in this country and another in Europe occur on the same day with the appearance of a spot on the sun. Tornadoes and sun-spots are so plentiful that there can be little difficulty in discovering coincidences between them. What if whirling tornadoes are accompanied by great electrical action: so are rotating dynamo-electric machines; but the relation of cause and effect is not solved by the comparison. In order not to be misunderstood in this connection, it may be well to state explicitly that there cannot be the least objection to the suggestion that sun-spots or electricity causes tornadoes; or that railroads increase the rainfall of the western plains. It would be a great misfortune to science if the right to make suggestions in explanation of natural phenomena were in any way curtailed or regarded with disfavor; but what does seem objectionable is the announcement of gratuitous, untested suggestions, as if they were worthy of belief. It does not seem too much to ask that

* Signal Service Note xix, 7; Science, x, 48; A. M. J., i, 550; ii. 54; vi, 104; etc.

if an observer believe in the efficacy of electricity for the generation of tornadoes, he should at least make a careful study of the action of electricity before publishing his suggestion, in order to carry out its proper deductive consideration, and then confront his deduction with the facts. If by this time the original suggestion is not abandoned, public announcement of it may be advisable.

5. *Ferrel's Convectional Theory of Tornado Generation.*— The theory of tornado generation advocated by Ferrel appears to us in marked contrast with the untested hypotheses above referred to; and as its essential elements are remarkably simple, popular appreciation of it has been hindered by a relatively remote publication and by insufficient presentation in more accessible literature. The chief writings by Ferrel on tornadoes are:

The motions of fluids and solids relative to the earth's surface. American Journal Science, xxxi, 1861, 27–51.

Cyclones, Tornadoes and Waterspouts. American Journal Science, xxii, 1881, 33–48.

These two articles are reprinted in Professional Paper XII, U. S. Signal Service, 1882.

Meteorological Researches for the use of the Coast Pilot. Annual Report U. S. Coast Survey, 1878, App. 10.

Annual Report of the Chief Signal Officer, 1885, pt. 2. "Recent Advances in Meteorology," 219–263.*

Ferrel's theory is based on the occurrence of an ascensional movement in the tornado whirl, of which there seems to be ample evidence. We are aware that Faye and others in Europe and Hazen in this country have questioned this fact, but it seems too well established to admit of a doubt. Many observers have recorded the visible upward flight of large objects, such as trees and boards, to considerable heights above the ground, whirling as they rose; while light bodies, such as clothing and paper, have been carried for miles. Whatever might be accomplished in this way by the upward deflection of a horizontal

* Professor Ferrel's latest work, A Popular Treatise on the Winds, has been published after the completion of this essay.

wind, it is safe to say that such is not the essential quality of the action in a tornado. The contrast between the horizontal outburst of the wind on the long extended front of a thunder squall (derecho) and the upward rush in the constricted center of a tornado is notorious; and while it is likely that some squalls have been described as tornadoes, as Hinrichs has shown,* there is no need of such confusion in well made observations. The upward motion about the center of a tornado is moreover proved in the same manner as in cyclones, by the continued oblique indraft, for which there must be some upward escape. The appearance of descent in the funnel cloud, so often sufficiently explained and as often misinterpreted, will be referred to later on.

The heavy clouds—"thunder heads"—that accompany thunder-storms and tornadoes, may be seen to boil upward distinctly enough, and are among the best indications of local overturning in the atmosphere. Observations continued through a single season are enough to demonstrate that a continuous series of upward movements may be formed, from the small cumulus clouds of summer mornings to the larger clouds of noon and to those huge masses with outspreading tops, giving forth lightning, thunder and rain. It is in the latter that tornadoes occur, seemingly as local developments where the ascensional movement is most powerful in the great cloud masses. While it is possible that ascensional movements may at times be caused in various ways, the association of the movements here referred to with increase of heat in the lower air, and their increase with increase of heat, make it manifest that they are convectional movements. We must therefore examine the theory of atmospheric convection in all its aspects and especially with regard to the conditions required for the most violent convectional motion; and then confront our deduced conditions with the conditions in which observations show that tornadoes occur. The correspondence then found will show whether we are on the right line of inquiry or not; and if right we may proceed

* Amer. Met. Journal, v, 1888, 313.

to inquire if violent convectional movement will produce the several characteristic features of tornadoes.

6. *Conditions of Convectional Motion in the Atmosphere.*—The first adequate general treatment of this subject was by Espy, in his "Philosophy of Storms" (1841), the introduction to which is still excellent and instructive reading. The most satisfactory quantitative statement of the matter is by Reye in his book on "Wirbelstürme" (1872), and these sources supplemented by an admirable graphic representation of the physical conditions of the problem by Hertz,* form the basis of the following considerations.

Long continued observation has shown that the atmosphere is generally of lower and lower temperature as we ascend above the earth, the average rate of decrease being 1° F. in 300 feet. Reye demonstrated that when the vertical decrease of temperature in the atmosphere is 1.6° F. in 300 feet—or 1° C. for 100 meters—then there is an indifferent equilibrium between the upper and lower strata of air; when the decrease is at a slower rate, the atmosphere is stable; when faster, it is unstable, and convectional motion may take place. This is because a vertical current—or a mass of air, rising or falling—must change its temperature as it changes its density in accordance with the variation of pressure upon it; and from the known rate of change of pressure with altitude, it is calculated that the change of temperature thus induced will be at the rate of 1.6° for 300 feet of vertical motion. Therefore, whenever the difference of temperature between adjacent strata of air exceed the rate of 1.6° in 300 feet, the lower stratum will be warmer and hence lighter than the upper, when they are brought to the same density, and the two will tend to change places: and when the change is affected, the vertical decrease of temperature will be slower than before and less than 1.6° in 300 feet of ascent. Changes of temperature of this kind are called "adiabatic," because they are produced without the passage of heat to or from the air, but simply by mechanical action on the air itself. Any

*Graphische Methode zur Bestimmung der adiabatischen Zustandsänderungen euchter Luft. *Met. Zeitschr.*, i, 1884, 421–431.

modern text-book on physics may be consulted for fuller explanation of this process.

The above figures apply to air not saturated with water vapor whether of low or high humidity; but when saturation is reached, the problem is changed by reason of the evolution of latent heat from the vapor that is condensed by further cooling. In that case, instability occurs with a slower vertical decrease of temperature than before, especially when the air is warm; for then a given amount of cooling causes a larger amount of condensation than the same cooling of cold saturated air. All this is thoroughly in accord with well tried physical principles; it has been abundantly tested by experiment, both on a small scale in the laboratory and, as we may say, on a large scale in nature; it is universally accepted by men eminent in physical study, whose original ability and careful studious work have led them to be regarded as authorities in their science, but who being authorities, have not thereby become arbitrary and irrational. It is, therefore, difficult to understand why the question should be so confused by Hazen, as appears in his recent articles.*

7. *Graphic Illustrations of Convectional Instability.*— Let us present the case graphically, taking first the case of non-saturated air. Let the horizontal line, figure I, be the scale of temperature, and the vertical line, the scale of altitude. Let AB represent the mean rate of vertical decrease of temperature in the atmosphere, as determined by observations in balloons and on mountains, namely 1° in 300 feet; and let CD and EF be the rates of cooling for the average of the colder months

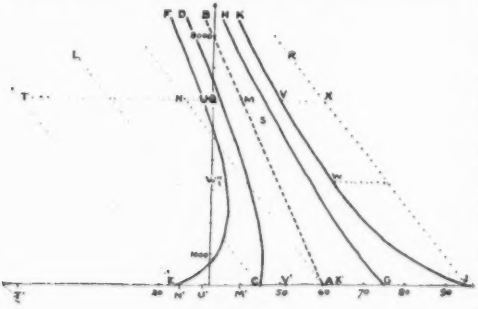


FIGURE 1.

* A. M. J., vi, 1889 105; Science, xiii, 488.

and for a cold calm winter night; while GH and JK are the same for the warmest months and for a hot summer day. It is manifest from the slope of these lines, compared with the slope of the dotted lines, all of which represent the adiabatic rate of temperature change in currents possessing vertical motion, that whenever the air is in its average condition, or on the winter side of that condition, it is stable; for at such time, there is no tendency to rearrangement between adjacent air strata. For example, at a time of average vertical decrease of temperature, suppose a mass of air be raised from sea level, where its temperature is A, to an altitude of 6,000 feet, where its temperature falls to N′. The temperature of the surrounding air at this altitude is M′, or N′ M′ degrees warmer than that of the lifted air: hence the lifted air is heavier than the air which it has entered, and it must sink all the way back to the ground before finding any air of its own density. In such conditions, there is no tendency to convection.

All the more stable is the air in a winter night: if the same experiment were then performed, the raised air would be U′ T′ degrees colder than its surroundings at the height Q. From this it appears that if we know the rate of vertical decrease of temperature in the atmosphere at any time, CD for example, we may say that the stability of the atmosphere is then represented by the left hand divergence of the adiabatic line, CL, from the line, CD.

Now take an example in which the line of vertical decrease of temperature in the air is not so steep as the dotted adiabatic lines: such a case is seen in summer days, when JK turns to the left of JR. V′ X′ then represents the excess of degrees of heat possessed by a mass of rising air over its surroundings when it has reached the height Q. At such a time, the air from the ground up to the height W″, where JK is parallel to JR, is all unstable; but the instability is strongest at the ground, where JK makes the largest angle with JR, because here the adjacent air strata are most unlike in temperature, the lowest being the warmest. Moreover, as the rate of ascent of such a mass of warm air will depend on its excess of heat, it is apparent that the surface air will ascend higher than that from any other

level, and that its ascent will be most energetic where JK and JR are farthest apart, as at altitude W″; and that the ascent will cease when the ascending and cooling air reaches air of its own temperature; that is when JK and JR intersect, as they will at some considerable height, above the limit of the figure. This full measure of height cannot be reached because the ascending current will be cooled not only by its own expansion but by conduction to and mixture with the air through which it passes. Some unknown allowance should be made for these effects, greatest in small and slowly ascending currents.

Now all these conditions of atmospheric stability and instability find abundant illustration. Nights are in general times of calm, because, in the absence of local convectional currents, the surface air remains on the ground, where any motion that it may have had is worn out by friction; but in the day time, local convectional currents spring up and by continually causing the descent of air from aloft to take the place of that which ascends, operate to maintain a breezy motion of the air at the surface. With the springing up of the day time breeze, we notice the appearance of little cumulus clouds; these grow larger as the day time temperature curve departs more from the adiabatic lines, and hence allows the convectional currents to rise in greater volumes to greater altitudes; and on hot afternoons, the clouds may reach mountain height; but as clouds indicate the condensation of vapor, we must now take up the consideration of the adiabatic lines of saturated air. From the time when Espy, forty years ago, thus explained the diurnal variation of the velocity of the surface wind, to the later dates when Hellmann in the same way explained the inverse variation on mountain tops, and Blanford explained the hot dry winds of India that run against the surface gradients, this theory of atmospheric convection has steadily gained ground.

Consider, therefore, the case of a mass of damp but not saturated air, rising from sea-level with a temperature A and dew-point T′, Fig. 2. As it ascends, it does work in pushing away the surrounding air to gain room for its expansion; and in doing this work, it must expend some of its energy. As long as its tem-

perature remains above its dew point, the energy expended is taken only from the heat of the expanding mass, whereby it is cooled. But on passing the dew point, a new source of energy capable of doing work, is found in the latent heat liberated by the condensation of some of the vapor. It is worth while to note that the dew point of the ascending air is not reached at the altitude, T″, where its temperature has fallen to the dew point, T′, that it had at the surface; for in ascending and expanding, the dew point falls, as is indicated by the line TB; not so fast as the temperature of the air falls, but fast enough to require a significant additional ascent to overtake it.* Suppose this is accompanied at altitude B″ and temperature B′. What change of temperature will now occur in ascending to altitude E″? As before, there must be some expenditure of energy to do the work of expanding against pressure; but now the energy is supplied partly by cooling the air and partly by the latent heat liberated in the cooling; the amount of cooling being less than before, and just enough to cause a condensation and thus liberate an amount of latent heat that will supplement its deficiency. It is a beautiful case of natural adjustment. In the first ascent, OB″, the energy needed in expanding was all taken from the sensible heat of the damp air, causing a fall of temperature AB′. In the further ascent, B″ E″, the energy needed corresponds to a further cooling of B′ E′, such as would take place if saturation were still not reached; but in the case under consideration, the energy needed is supplied in part by a cooling of B′ F′ degrees, as a consequence of which there will be vapor enough condensed to liberate latent heat corresponding to the further cooling, F′ E′. Hence after reaching the dew point, the cooling of an ascending mass of air is retarded to the rate BD. It is a mistake to say that the latent heat thus lib-

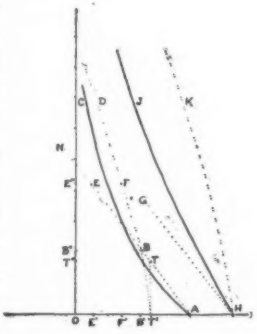


FIGURE 2.

*Espy, Philosophy of Storms, 1841, ix. Hertz, Met. Zeitschr., I, 1884, 429.

erated will warm the air enough to allow the condensed vapor to evaporate again; for the latent heat is completely expended in the work of pushing away the air that surrounds the ascending expanding mass, and therefore cannot be applied to any other task. Espy made this error for a time, but afterwards corrected himself. It is regrettable to see the error now revived by Hazen.

The retardation of cooling thus accomplished is greatest in warm air, where the condensation of vapor, and hence the liberation of latent heat, is greatest for a given fall of temperature. Thus in saturated air at 80° and at sea level, the adiabatic cooling is only at the rate of 0.7° in 300 feet; while if the temperature is 32°, the rate is 1.1°. This is a most important matter in physical meteorology, and if any of our readers feel in doubt about it, it will be well for them to study it out thoroughly. The text-books in current use unfortunately say little on the subject, but it is abundantly demonstrated by physicists and meteorologists. A mathematical discussion of the problem by Hann has been translated by Abbe for the Smithsonian Report for 1877.

The most important consequence of this retardation in relation to the subject in hand is that it aids convectional currents by introducing instability where non-saturated air would be stable and quiescent. This may be understood by a glance at figure 2. For example, if the vertical decrease of temperature in non-saturated air be HJ, it will be stable, because HJ turns to the right of the adiabatic line HG; but if the air be saturated it is unstable, because HJ turns to the left of the adiabatic line HK.

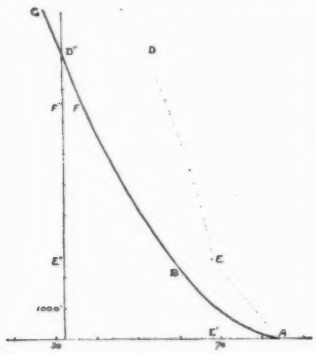


FIGURE 3.

Another important consequence is the greater altitude that may be reached by an ascending column of saturated than of non-saturated air, as appears in figure 3. For example, on a hot summer afternoon, when the vertical decrease of temperature in atmosphere is indicated by ABFG, the air is unstable,

and by ordinary convection the surface layers may ascend to altitude F″, supposing that then dew point is not even reached. This probably represents the condition on torrid deserts where the air is very hot and dry, and where the sky remains cloudless though dulled with dust that is carried aloft in convectional whirls. But if the surface air be moist, and its dew point is reached at altitude E″, then further cooling is retarded, as indicated by the line ED, and the ascending mass may reach a great altitude above the limits of the diagram before finding any air of its own temperature. It is undoubtedly for this reason that thunder-clouds rise to so great a height before spreading out laterally in the cirro-stratus cover by which they are terminated.

Still another important consequence is seen in the change of the locus of maximum instability. The greatest horizontal distance between ABF and AEF is about at the altitude E″, which thus indicates the altitude of maximum energy of ascent in the air that rises from the surface: but the greatest horizontal distance between ABFG and AED is about at the altitude D″, or perhaps three times as high as before. We can understand from this that in ordinary conditions of the atmosphere, when the rate of vertical decrease of temperature is fastest at the surface, it is the surface air that can reach the greatest height by convectional ascent: also, that when cumulus clouds are forming, they will grow slowly if, as must be commonly the case, the instability of the atmosphere is not strongly marked; that is, if AED does not at any point depart greatly from ABF; and it is only in cases of the most pronounced instability that the rapid boiling up of thunder-heads is permitted. Indeed, it appears reasonable to say that the normal form of cumulus clouds of convectional origin is the hour-glass shape, seen best in thunder-storm clouds; but not realized commonly, where instability is less distinct, where the consequent slow ascent is in good part overcome by the inert weight of the cloud drops, and where the small mass involved is much affected by mixture with the conduction to the surrounding air, for all of which reasons it fails to ascend to its normal height, where it might spread out horizontally.

(TO BE CONTINUED.)

TORNADOES IN INDIANA.

STATE TORNADO CHARTS.—INDIANA.

By LIEUT. JNO. P. FINLEY, Signal Service, U. S. A.

TABLE I.—*Tornadoes in Indiana.*

Period of observation, 71 years, 1818–1888.
Total number of storms,—94.
Year of greatest frequency, 1886,—29 storms.
Average yearly frequency,—4.5 storms.
Year in past ten (10) years, no report of storms,—none.
Month of greatest frequency, May,—26 storms.
Day of greatest frequency, May 12th, 13 storms.
Hour of greatest frequency, 5 to 6 P. M.
Months without storms,—January.
Prevailing direction of storm movement, NE.
Region of maximum storm frequency, central portion.

TABLE II.—*A Chronological Table showing the location, date and time of occurrence and general character of formation and movement of Tornadoes in the State of Indiana, for a period of 71 years, from 1818 to 1888.*

County.	Month and Day.	Year.	Time.	Direction.	Form of Cloud.	Width of Path in Feet.
Hendricks	August —.	1818 or 1819				
Putnam	August 27.	1827	Afternoon.	NE.		2,640.
Clark	October 15.	1835	8 p. m.	NE.	Funnel.	300.
Posey	April 30.	1852	5 p m.	E 10° N.	"	1 500 to 5 280.
Franklin	"	1852	5 p. m.	E 10° N.	"	1,500 to 5 280.
Vigo	April 16.	1860	6:30 p. m.	NE.		60.
Posey	June —.	1867	9 p m.	E 25° N.		200.
Putnam	September 3.	1867	Night.	NE.		1,320.
Switzerland	June 11.	1874	2 p. m.	E		600.
St. Joseph	July 26.	1874				
Switzerland	June 29.	1875				
Fountain	July 27.	1875	Afternoon.	SE.	Funnel.	800 to 1,200.
Elk Hart	October 29.	1875	11 a. m.	NE.	"	
Gibson	February 27.	1876	Afternoon.	NE.	Inverted Funnel.	300 to 600.
Hamilton	May 6.	1876	5 p. m.	E 20° N.	Funnel.	
Henry	July 4	1876				
Allen	June 18.	1877	Afternoon.	NE.		
Sullivan	June 25.	1877	5 p m.	NE		
Allen	"	1877	Afternoon.	NE.		
Wayne	June 30.	1877	7:30 p. m.	NE.		
Morgan	"	1877	9 p m.	NE	Balloon.	300 to 1,320.
Ripley	July 1.	1877	Afternoon.			
La Porte	July 2.	1877	"			
Elk Hart	"	1877	5:30 p. m.	SE.	Funnel.	600 to 800.
Elk Hart	"	1877	6 p. m.			
Harrison	February 21.	1878	4 p. m.	NE.		100 to 300.
Posey	May 18.	1878	Afternoon.	NE.		
Gibson	December 26.	1878	3 p. m	NE.		
Vigo	November 14.	1879	a. m.	NE.		
Orange	"	1879	Morning.	NE.		
Jackson	November 28.	1879	Noon.	NE.		600.
Marion	March 4.	1880	10:30 p. m.	NE.	Funnel.	
Wayne	April 19.	1880	Afternoon.			
Shelby	June 14.	1880	"	NE.	Funnel.	300 to 500.
Hamilton	"	1880	"			
Clinton	"	1880	"	NE.	Funnel.	
Posey		1881		ENE.		

TABLE II.—*Continued.*

County.	Month and Day.	Year.	Time.	Direction.	Form of Cloud.	Width of Path in Feet.
Allen	May 27.	1882	2 p. m.	.....	.....	82.
Posey	July 23.	1882	9:20 a. m.	.....	Funnel.	.....
Elkhart	May 14.	1883	2 p. m.	E 15° N.	"	100 to 660.
Wayne	"	1883	7 p. m.	NE.	.....	2,640.
Wayne	"	1883	4 p. m.	E 20° N.	.....	.....
Marion	"	1883	Evening.	NE.	Funnel.	300.
Johnson	May 28.	1883	.....	SE.	.....	.....
Jackson	June 10.	1883	6 p. m.	E.	Funnel.	.....
Jennings and Ripley	"	1883	7 p. m.	NE.	"	900.
Gibson	August —.	1883	.....	NE.	.....	.....
Jackson	October 14.	1883	.....	NE.	.....	.....
Decatur	March 25.	1884	4:30 p. m.	NE.	.....	60 to 360.
Marion	"	1884	3:45 p. m.	.....	Funnel	.....
Delaware	April 1.	1884	5 p. m.	ENE.	"	600 to 2,600.
Hamilton	"	1884	4 p. m.	NE.	"	1,320.
Jennings, Ripley and Dearborn	May 10.	1884	.....	NE.	.....	.....
Clay	July 26.	1884	2:30 p. m.	SE.	Funnel.	.....
Posey	November 6.	1885	5:40 p. m.	.....	.....	.....
Warren	March 20.	1886	5:30 p. m.	NNE.	Funnel.	165 to 330.
Switzerland	"	1886	4:30 to 6:10 p. m.	NE.	"	600.
Adams	"	1886	5:30 p. m.	NE.	"	.....
Wells	"	1886	5 p. m.	NE.	"	100 to 450.
Rush	May 9.	1886	5 p. m	NE	Whirlwind	.....
Fayette	"	1886	4:30 p. m.	Easterly.	.....	.....
Warren	May 12.	1886	6 p. m.	NE.	Funnel.	2,640.
Marion	"	1886	Afternoon.	NE.	"	.....
Hancock	"	1886	5:30 p. m.	NE.	"	1,320.
Miami	"	1886	Afternoon.	NE.	"	.....
Fountain	"	1886	10 p. m.	NE.	Balloon.	2,640.
Hamilton	"	1886	8 p. m.	ESE.	.....	225 to 600.
Madison	"	1886	6:45 p. m.	ENE.	.....	.....
Warren	"	1886	10 p. m.	E.	Funnel.	.....
Jay and Randolph	"	1886	Afternoon.	NE.	"	.....
Carroll	"	1886	6 p. m.	NE.	Balloon.	Narrow.
Shelby	"	1886	9 p. m.	NE.	Funnel.	5,280.
Hamilton	"	1886	5:30 p. m.	Easterly.	.....	.....
Madison	"	1886	7:15 p. m.	NE.	Funnel.	2,640.
Jay	May 14.	1886	8 p. m.	NE.	.....	500.

TABLE II.—*Concluded.*

County.	Month and Day.	Year.	Time.	Direction.	Form of Cloud.	Width of Path in Feet.
Fountain	August 12.	1886	8:15 p. m.	NE.	Funnel.	2,640.
Warrick	August 14.	1886	5 p m.	NE.	"	.....
Fayette	August 22.	1886	3:25 p. m.	ESE.	"	200.
Union	"	1886	6 p. m.	E 20° S.	"	600.
Vermillion and Parke	September 16	1886	11:35 a m. to noon.	NE.	"	.....
Fountain	"	1886	4 p. m.	NE.	"	Narrow.
Vigo	"	1886	11:30 a. m.	NE.	"	.....
Madison	"	1886	8:15 p. m.	Easterly.	"	2,640.
Adams	September 22.	1886	Afternoon.	NE.	"	.....
Shelby	February 11.	1887	4 a. m.	NE.	"	2,640.
Monroe	April 22.	1887	6:30 p. m.	NE.	"	375 to 2,640.
Vanderburgh	April 25.	1887	10 a. m.	NE.	"	90 to 120.
Carroll	August 5.	1887	Evening.	NE.	"	1 320 to 2,640.
Vanderburgh	February 24.	1888	Afternoon.	NE.	"	Narrow.
Fayette	April 5.	1888	7:30 p. m.	NE.	"	900 to 1,320.
Carroll	"	1888	5:30 p. m.	NE.	"	1,320.
Rush	"	1888	7:20 p. m.	Easterly.	"	1,320 to 2,640.
Porter	May 11	1888	Evening.	NE.	"	2,640.
Tipton, Grant and Madison	August 6	1888	10 p. m.	NE.	.....	1,320 to 2,640.

TABLE III.—*Relative frequency of Tornadoes by months and days, for Indiana.*

The index figures to the right and above the dates show how many times tornadoes occurred on that day of the month.

Month.	Day of Month.	No. of Days.	Total No. of Tornadoes per month.
February	11, 21, 24 and 27	4	4
March	4, (20)[4] and (25)[2]	3	7
April	(1)[3], (5)[3], 16, 19, 22, 25 and 30	7	11
May	6, (9)[2], 10, 11, (12)[13], (14)[5], 18, 27 and 28	9	26
June	(10)[2], 11, (14)[3], 18, 22, (25)[2], (30)[2] and (—)	8	13
July	1, (2)[3], 4, 23, (26)[2] and 27	6	9
August	5, 6, 12, 14, (22)[2], 27 and (—)[2]	7	9
September	3, (16)[4] and 22	3	6
October	14, 15 (?) and 29	3	3
November	6, (14)[2] and 28	3	4
December	26	1	1
Blank (—)	(—)	1	1
Total		55	94

NOTE.—The blank (—) signifies date missing.

THEORY OF STORMS, BASED ON REDFIELD'S LAWS.

By H. Faye, Membre de l'Institut, etc.

(continued from November number)

2. *Mechanics of Whirls in Flowing Water.*

The only forces in play in the production of whirls in flowing water are the inequalities of velocity of the water currents where they originate. Their *rôle* is to store up these inequalities of velocity in a vast funnel, and to convey to its lower part the energy concentrated upon a limited area, and to exhaust this energy in work upon any resisting body. The result is to render the flow of the stream more uniform in retarding its current. Instead of considering this phenomenon in its entirety we will begin by examining how these differences of velocity can engender gyrations.

Let us consider that in all streams there are molecules animated by different velocities—*A*, *B*, *C*, *D*, ... in the direction of the current.

FIGURE 1.

To disembarrass ourselves for the moment of the general transference of these molecules, we will take the mean *M*, of all these velocities, and apply it in the inverse direction to each. The current, properly speaking, will disappear for them. There will remain only the differences *A*—*M*, *B*—*M*, *C*—*M*, *D*—*M*. . . . the first two negative, the two others positive, that is, in the direction of the current.

Associate these opposing velocities two by two in parallels forming couples with a vertical axis, tending to produce rotations in the same direction. It may happen then, that the neighboring couples are so arranged among themselves as to form several resultant couples more intense, or even one single couple in which will be summed up all the partial energies. If we next give to all these molecules their mean velocity *M*, nothing will be changed as to the rotation obtained, but these gyrations will put it in motion as a whole with the mean velocity

in the direction of the current. This is what is represented at the right of the figure.

As to the direction of the rotation, it will depend on which side the greatest velocity is found. In the figure it follows to the right of the spectator looking at the water flowing before him; the rotation takes place from right to left (direct motion), as in the cyclones of our hemisphere.

But we have not yet a veritable whirl; that of which we have just spoken would give rise to a mass animated by a simple movement of rotation around a vertical axis. It is necessary to insist upon this difference.

In the case of a fluid mass animated by a simple rotation, a thing easy to realize in turning for a time a vase containing that mass; the free surface ceases to be plane; the water at the circumference rises along the wall of the vase, while the water of the center is lowered. Analysis, perfectly applicable here, shows that when the equilibrium is attained, the surface takes the form of a paraboloid of revolution. Each molecule describes circle around the axis with a linear velocity proportional to its distance from the axis. The angular velocity is everywhere the same. The liquid mass turns with the same movement as would a solid body.

The whirls of our water-courses are quite different. Their free surface is not paraboloidal, but conic, in form of a funnel. The angular velocity of each molecule is not a constant; it increases toward the axis in an inverse ratio to the square of the radius. Finally, there can be no question, as in the preceding case, of a state of equilibrium where all the layers turn horizontally; here all the strata are animated with a descending movement, and the particles of the free surface soon cease to belong to it, and are drawn down. Below, in contact with the ground, the whirling movement undergoes a sudden transformation. The water escapes tumultuously from the whirl, in virtue of its acquired velocity, and spreads itself over the surrounding medium, which may be considered unlimited.

All those who frequent streams, engineers, boatmen, and swimmers, know perfectly that whirls descend, and that they swallow

up bodies lighter than water which they encounter in their path. It can not here be a question of a tendency toward a sort of equilibrium; a whirl is a dynamic apparatus for the transmission of force acting from above downward.

How will these gyrations comport themselves on descending in the interior of the whirl? We shall see that farther on, in the detailed study of the facts.

Let us now content ourselves by saying that the centrifugal force is there counterbalanced by the pressure of the surrounding fluid; as this augments with the depth, the velocity of gyration increases with rapidity from the mouth to the foot of the whirl,—while above, at the mouth, the whirl tends little by little to become enlarged.

It were much to be desired that the equations of hydrodynamics might be applied to these questions. We could thus arrive by analysis to the demonstration of the laws which observation reveals,—and still farther. But here I present an obstacle now actually insurmountable, which has been referred to above; we approach the limits of the science. We will try nevertheless, to form some idea of the descending movement which characterizes the whirls of our hemisphere.

A force is evidently necessary to draw down a part of the water from the upper stata. This force is borrowed, as is the gyration itself, from the differences of velocity of the threads of the current. When the liquid threads or layers, animated by different velocities, are deviating toward a center of gyration those of which the absolute velocity is the greater (to the right in the preceding figure) mount or climb upon those whose velocity is less*; these others sink, and fall in such a way as to form a sort of a conical funnel toward the bottom, to which the threads descend, in taking a gyration more and more lively. The water engaged in the whirling of the mouth descends towards the bottom of the funnel, which always empties itself without power to refill, for, by its weight, the mass con-

* This is a phenomenon analogous to the bore, which is formed at the mouth of certain rivers at the approach of the flux, or more simply the folding back of the waves which break upon the shore.

stantly renewed, presses upon the lower spirals and propagates downwards the descending movement. If the gyration dies out, the descending movement is arrested or the whirl remounts toward the mouth; this will end in forming above the surface of the water, in virtue of the velocity acquired, a small conic protuberance which will disappear in an instant.

But if the gyration is lively the whirl would descend indefinitely until arrested at the bottom. It is then a veritable organ of vertical transmission of the force stored up in its vast throat, under the form of gyration. But this explanation of the descent of the whirling spiral is far from complete. We will finish it later in studying more closely what occurs at the center of a cyclone and by means of experiments made directly upon the liquid whirl, conveniently modified.

However it may be, the whirls of water courses present a striking analogy to those of the atmosphere.

It remains for us to show that there exist, in the upper regions of the air, vast currents, where such whirls may originate, by identifying them absolutely with our tempests, as much in the direction of their gyrations as in that of their trajectory.

3. *Upper Currents of the Atmosphere.*

The equilibrium of the atmosphere, disturbed unceasingly by the action of the sun, tends to re-establish itself by a circulation of which we will seek the principal marks at the equator, towards which the lower trade-winds converge. The air is there animated only by an ascending movement due to solar heat, it rises during the day above the surface of the barometric level or that of equilibrium, and tends to spread on each side toward the poles, flowing on these surfaces by force of gravity. It is replaced below by air from the trade-winds, which come laden with moisture. Hence a continual circulation by means of which the effect of the alternations of day and night, disappears, but which undergoes the changes of seasons.

I do not believe that the upper nappe of the overflow falls back upon the earth in temperate climates, to feed the trade-winds and to produce the prevailing winds from the west.

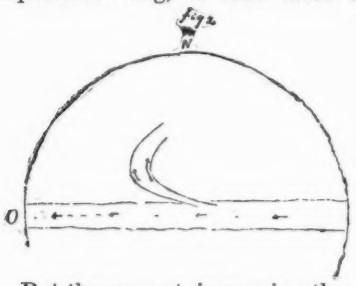
The air, flowing from the equator, spreads over a barometic

surface, because of the height to which it is elevated above that surface; but it could not fall below and penetrate, of itself, the lower strata. To draw it down requires a force of which I do not perceive the *raison d'être*. If the lack of symmetry of the terrestrial surface is considered, it will be readily admitted that on the two nappes of dispersion towards the two poles, currents may form in the aerial streams, and of these we are to study the nature and direction.

First it may be noticed that it is in the equatorial area fed by the trade-winds that will be collected, so to speak, the moisture brought by the winds which come to die in this area, after having passed over the seas. This humidity ascends with the air and condenses in clouds at a certain altitude. The clouds, exposed to the ardent rays of the sun, vaporize and, step by step, by a sort of distillation, their vapor condenses at a greater altitude, in the form of ice-needles. These are the cirri which invade at an altitude of from 12 to 15 thousand meters, the equatorial ring formed by the ascending air above a barometric surface of which it is impossible to assign the height, unless that of the cirri themselves has been measured. The ring which is dispersed from the equator could not have formed without lifting the air situated above it. The upper air, more rare, and not weighted by the cirrus, operates as the regulator and diminishes the effect of the diurnal variations. If this ring is considered by itself, as air,—and the ice-needles which form it coming from below where the daily linear velocity of rotation is less than at an altitude of 12 to 15 thousand meters,—it will be behind in the general movement of the atmosphere and will seem animated by a movement towards the west—feeble, it is true, but sensible, something like one or two meters per second. The recent phenomena at Krakatoa seem to confirm the existence of a similar movement in the very elevated strata at the equator; this is, at least, the conclusion in a recent memoir by Dr. Braun upon the eruption of this volcano, and upon the progress of the fine dust which was projected to great heights in the equatorial regions.

Thus, in taking a pole-ward stream by itself, passing from the

equatorial ring, we find there a constant but feeble velocity toward the west; then a velocity due to the fall towards either pole, in gliding over the barometric level, form the point of departure. This current will begin with a westward direction but will turn more and more towards the pole.



But the current, in nearing the pole, will have at each point an excess of linear velocity towards the east, in comparison with the molecules of air situated upon the same parallels. The excess of velocity due to the rotation of the globe, at first almost imperceptible near the equator, ends nevertheless by canceling the first velocity towards the west. Now the current would go direct to the pole, but the two velocities composing it, the one towards the pole, the other towards the east, regulate the trajectory, and the latter will be directed towards the NE, or, better still, towards the points situated between the pole and east.

Should a whirl form in the current, it will describe precisely the trajectory of a storm, in following the direction of the current.

Finally, since the aerial stream makes a marked bend towards the east, it is the threads on the left which have the least velocity; consequently if a whirl is formed there, the gyrations will be from right to left in our hemisphere, and from left to right in the opposite hemisphere. Such is also the direction of the gyration of storms.

We conclude that cyclones are whirls, descending with vertical axes, originating in the upper currents of the atmosphere.

However, we must connect with this simple mechanical conception, the variety almost indefinite of physical phenomena which accompany storms. To fix this idea, I will suppose that the air, taken at an altitude of 10,000 meters, and which has a temperature of —30° C. and a pressure of 219 mm., be drawn to the lowest stratum of the atmosphere at 760 mm. and at + 25°. In passing through the strata more and more dense, it will sup-

port an increasing pressure. The compression experienced developing heat, the well known formula of LaPlace or of Poisson shows that at the moment when the air attains the pressure of 760 mm. its temperature will be 78°, that is 53° more than the surrounding air (25°), and its dryness will be extreme. It is supposed in this calculation that the descending air has lost no heat, neither by radiation nor by exchange, with the strata of air traversed. In reality it is not so, and the excess of temperature is never so considerable in small cyclones which are formed over the deserts of Africa or Asia, and which are named sand-storms or simooms. The following is a description of them:

In the midst of a profound calm, and a suffocating heat, the storm is announced by the appearance in the sky near the horizon of a dark cloud of unusual aspect. The cloud ascends and grows: soon it covers the sky with a veil of dust thick enough to obscure the sun, and to give passage only to a gloomy light. The barometer falls more and more; the wind blows violently; the thermometer rises at times to 50° C.; the dryness becomes excessive; the evaporation of water is doubled; wooden furniture, rapidly dried, twists and cracks; skins shrivel up; and upon living objects the effect is still more serious. The burning wind carries with it a fine dust which fills the eyes and throat, producing an insupportable prickling sensation. It is really impossible to face this furnace heat. When a caravan is surprised in the desert by a simoom, the Arab covers his head with woolen cloths. The camel cowers and buries his nose in the sand, seeking a less burning temperature. The storm passes, and it is calm, the sand carried on by the wind falls again, the sky clears, and the spectator, raising his covering, sees that the appearance of the desert is changed. The dunes have disappeared or have changed their place. The sand-storm has executed, in its passage, a vast work of leveling.

The phenomena of this order do not present themselves except in instances where the upper currents carry but little cirrus, and where the lower air is relatively dry. But the general rule is, that cyclones are the seat of an abundant precipitation

of the vapor of water, and carry down air that is colder and more humid than the surrounding air. There is no contradiction in making cyclones which are mechanically constituted in the same manner,—blow here, air that is warm and dry, and there, air that is cold and charged with moisture.

The difference is, as has been represented, in the rarity or abundance of the cirrus of the generating currents. In the second case, that of ordinary storms, the abundance of cirrus is the regular condition; here it is a warning signal, to which mariners attach great importance. Cyclones are, in fact, announced five or six days in advance, (at least in the tropics), by the appearance of cirrus. It is even a fact so constant that meteorologists have believed that it is the cyclones which produce the cirrus!

The cirrus at — 30° C., collected in the mouth of a cyclone, melts or dissolves on descending to the warmer strata, in proportion as the temperature of the air carried away augments by compression.

It determines in its passage the condensation of the moisture of the lower strata, and even in certain cases, transforms the clouds into ice. Hence the theory which is given farther on of thunder-storms, floods and hail.

(TO BE CONTINUED.)

METEOROLOGY AT THE PARIS EXPOSITION.

By A. Lawrence Rotch.

(CONTINUED FROM NOVEMBER NUMBER.)

II. THE FOREIGN SECTIONS.

The small exhibit of the foreign countries suffers by being scattered over a large area, rendering the instruments difficult to find and to compare with one another.

The exhibit of the United States Signal Service is meagre and gives no adequate idea of the scope of its work. The instruments shown are a barometer and the new triple register for wind velocity and direction and rainfall. There are also charts and other publications of the Service. General Greely explains this unsatisfactory representation of the work and

methods of the Signal Service on the ground that the Signal Office had no money and received no direct encouragement from any one and only made the exhibit at the last moment when urged to do so by a representation of the French Government. The exhibit, therefore, consists only of such articles as could be gathered together without expense and at that time, also, by misfortune, the office was busy moving, with its instruments and records scattered.

Next to Richard brothers the most extensive collection of registering meteorological instruments is that of Usteri-Reinacher, the successors of Goldschmidt and of Hottinger, of Zürich, Switzerland. In the aneroid barograph and thermograph shown by this firm the method of enclosing the clock in the cylinder carrying the register sheet and the transmitting mechanism from the motors actuated by pressure or temperature are similar to those employed by Richard brothers, the priority of invention being claimed by both makers. It is to be noted, however, that the Swiss instruments have been put in the market but recently and that their price is considerably higher than the French instruments, the barograph costing 185 francs ($37) as compared with 125 francs ($25) for the corresponding Richard instrument. In the thermograph the motor is not the curved tube with alcohol employed by Richard but a compound bar of dissimilar metals bent in a circle. The pluviograph has a tilting bucket resting on a coiled spring. After a certain quantity of water has entered from the receiver the weight of the bucket causes it to compress the spring and to descend, when it empties itself and returns to its original position. The motion of a pencil on the spring is recorded upon a vertical cylinder covered with paper and turned on its axis by clockwork. This pluviograph would seem efficient when no snow is to be recorded and its cost 200 francs ($40) is less than that of other recording gauges. The English photographic sunshine recorder, or heliograph, of Jordan, has been modified by Dr. Maurer, of Zürich, so that instead of the two curved traces representing the morning and afternoon sun, respectively there is but a single straight trace for the whole day. The,

instrument consists of a cylinder, larger than the English one, with its axis parallel to that of the earth and cut by a horizontal plane in which a hole permits the sun's rays to reach the blue print paper contained in the cylinder. This paper is insorbed by removing a cover at the lower end of the cylinder, but this is inconvenient and can hardly be done without displacing the instrument from the meridian and it would seem better to have the cylinder removable from the socket so that it could be taken indoors to change the paper. The price of this heliograph (66 francs or about $13) is less than one-third that of the burning heliograph of Campbell.

Two instruments for direct observation made by Usteri-Reinacher merit notice. The hair hygrometer of Dr. Koppe is probably the best of its kind and costs only 45 francs ($9). It combines a simple method of testing its readings at saturation by means of a frame covered with muslin which forms the back of the case. When this is wet the contained air is saturated and the index is adjusted to indicate 100. In the Goldschmidt aneroid barometers, which are much used by engineers and surveyors, the reading is rendered very fine by means of a micrometer screw and a microscope. The price of the pocket size is 100 francs ($20), and that for surveyors' use 150 francs ($30). A table of temperature corrections is furnished with each barometer, but we know of one instrument in which the errors instead of the corrections were given, thus doubling the error of the corrected observation.

The Dutch house of H. Olland, of Utrecht, which is well known for its construction of balances of precision and of meteorological instruments, particularly of the telemeteorograph, which transmits by a single wire to a central station the indications of various instruments, shows two sets of registering meteorological apparatus. One of these, the anemometrograph, gives a graphic representation of the direction, force and velocity of the wind. The direction is noted by one of three pens fixed on an endless ribbon and moved by the vane. If the wind rotates more than 360°, the pen which first marked the direction is replaced by a second. The anemometer is con-

structed on Oster's and Robinson's systems. The spring which measures the force of the wind is placed behind the plate and below the vane. This spring, shaped like a carriage spring, is of tempered steel, and is so adjusted that for light pressure the pen moves farther than for heavier pressures, by which means the former is noted more exactly. The transition from light to heavier pressures is indicated in a regular manner, so that, for example, it decreases for each 5 kg. increase of pressure. The registration of wind velocity is made with an open circuit so that in a calm, the contact remaining closed by the Robinson cups, it does not use up the battery. The registration is made so that high and low velocities are equally legible, though the paper moves but 8 mm. per hour. In the wind wheel the contact occurs after each 150 revolutions, which corresponds to about 500 m. travelled by the wind. By each attraction of the magnet the pen is displaced laterally, first ten times to the left, then ten times to the right; when, therefore, the pen has completed its to-and-fro movement and returned to zero, the wind has travelled 10,000 m. For low wind velocities, 500 m. correspond to each lateral movement. With this instrument endless bands of paper or rolls for a week can be employed, which are divided into hours by the clock causing the three pens placed in front of the instrument to mark across the paper. The division for the indications of the instrument is made beforehand. The registration is made in ink so that it is very distinct. The pens used were invented in 1887 for this apparatus, but have since been employed elsewhere with success.

The baro-thermometrograph shown is a combination of the balance barograph and the balance air thermometer, with sliding weight on Dr. Sprung's principle. The tube of the barometer is suspended from a balance and as the mercury rises or falls and, in consequence, the tube becomes heavier or lighter, the escapement of a clock movement is liberated and displaces the weight on the balance beam until this is in equilibrium when the wheels are stopped. The pen follows the motion of the running weight and thus traces a line which corresponds to the varying heights of the barometer. The air thermometer is

composed of a large glass reservoir connected by a very small tube with the top of a barometer tube whose mercury oscillates with the temperature changes of the rarefied air in the reservoir. The height of the mercury column does not exactly indicate the temperature, for the mercury is also subjected to the atmospheric pressure. To neutralize this influence the barometric tube forms part of the apparatus, the tube of the registering barometer and of the air thermometer having the same diameter. When the atmospheric pressure changes, the same quantity of mercury flows from each of the tubes into the buckets placed below and suspended to the ends of an equal-armed balance. This balance, therefore, remains in equilibrium with a change of atmospheric pressure, but if a change of temperature causes the mercury to flow out of the thermometer tube the equilibrium is destroyed and the running weight is displaced with the result before described. The paper can be made to last any desired time, the division into hours being done by the clock and the registration effected in ink.

In the Russian section, J. Timtchenks exhibits an anemograph for which he claims the originality of registering by a single symbol upon a revolving drum both the direction and velocity of the wind. Though this claim cannot be sustained since the principle of registering the direction and velocity by an arrow is used in other anemographs, yet the mechanism of this one is compact. The spindle of the vane, constructed on Sallerou's system, that is a fan wheel on a horizontal axis, descends into the observatory and carries a disk divided to the points of the compass which permits the direction of the wind to be read directly from a fixed index. On the end of this spindle is a hollow cylinder having an engraved arrow which is sustained by a fork and also rests on a cloth-covered disk saturated with ink. Beneath is a drum turned on its axis by clockwork once in twelve hours, and covered with paper which is divided by transverse lines into hour and half-hour periods, and by longitudinal lines into twenty-four hours. During twenty-four hours the drum makes two revolutions and by means of a screw has a progressive movement which advances it on its axis dur-

ing sixty-four turns, so that the clock need be wound up only each thirty-two days. The anemometer has Robinson cups which complete an electric circuit for each one hundred revolutions, and by means of the action of an electro-magnet upon a system of levers and eccentrics, the ink disk turns aside, the cylinder falls on the paper and imprints the arrow indicating the wind direction. This done, the cylinder rises and the ink disk comes again under its extremity. The length of contact depends generally upon the wind velocity but the registering mechanism is so constructed as to make but one turn independently of the length of contact, always employing the same length of time and imprinting but one arrow. The apparatus being oriented, the arrow printed on the paper will indicate the wind direction and the number of these arrows recorded in a space representing one hour gives the data for determining the wind velocity from a table prepared when the Robinson cups are tested. The anemograph costs about 2000 francs ($400) and it is apparently in use at the Odessa Observatory, since a description has been prepared by Prof. Klossovsky of that institution. A pluviograph is shown by the same constructor but with no description of its action.

Two registers for a maregraph, etc., on the principle of Dr. Sprung's barograph, are exhibited by J. A. Neergaard, of Copenhagen. Two curious thermometers are seen in the Russian and Grecian sections. The first is the rotation maximum and minimum thermometer of Rabinowitch, which has a hollow jacketed bulb filled with alcohol, and a stem, bent into a circle, containing mercury. The thermometer revolves in a frame about an axis on the bulb and the end of the stem which forms the index moves over a graduated arc and marks, by means of two movable indices, the amplitude of its oscillations, which are determined by the change of centre of gravity due to the movement of the mercury in the tube. The pocket thermometer of H. Pieroni, of Athens, has two bi-metallic bars fixed at the upper ends, and connected at the other ends with a sector which, through the medium of a coiled spring, operates a needle on a dial graduated to Reaumur degrees. The whole is contained in

a silver coin about the size of a silver dollar and is sold for 30 francs ($6). The motor and transmitting mechanism are similar to those of the thermograph manufactured by the Draper Mfg. Co., of New York. As a pocket instrument it is larger and less sensitive than the English clinical thermometer of Immisch, whose motor is a curved tube filled with alcohol with one end free to move.

Corrections to Part I.—In the recent models of the Richard anemometer for the vertical component of the wind, the cross-piece actuated by the electro-magnets is replaced by a vertical axis carrying a crown-wheel with four teeth. The armatures of the three electro-magnets press on the wheel and turn it in the direction in which the currents successively enter the magnets. A fourth electro-magnet locks the crown-wheel by engaging teeth on its under surface. In order not to exhaust the battery by continuous currents, each magnet breaks the circuit which operated it and prepares the two others for action.

In the Bourdon anemograph as now constructed the aspirations produced by the Venturi tubes is transmitted to a curved tube of elliptical section, which is fixed at one end, but whose free end is connected by levers with the registering pen.

DISTRIBUTION OF AVERAGE WIND VELOCITIES IN THE UNITED STATES.

INVESTIGATED BY DR. FRANK WALDO.

(CONCLUDED FROM NOVEMBER NUMBER.)

SECTION VI. INCREASE OF WIND VELOCITIES WITH ELEVATION IN U. S.

The study of the increase of wind velocities with elevation is of the utmost importance; for, the law of this increase must be known before we can attempt to make a reduction of wind velocities to some common level, as is done for pressure and temperature. There are several ways of looking at this matter, and I

shall take up the question as illustrated by data obtained in the United States.

On the eastern coast we have an opportunity to compare wind velocities at sea level and at elevations of 600 and 6,300 feet: Thatcher's Island (or perhaps in its place Block Island), Blue Hill, Mass., and Mt. Washington. It would seem as if this combination offers a tolerably good opportunity to determine the increase of wind above the eastern coast waters.

For the centre of the continent there is the slope of the Great Plains for determining the law of variation of wind velocities on gradual slopes. Also, Pike's Peak gives us the wind at a great elevation, for this region.

On the western coast, the observations at the Lick Observatory on Mt. Hamilton (unfortunately not available for the present paper) will probably be used in the future investigations of this subject. The only wind data now obtainable is for the moderately elevated station at Cape Mendocino, which seems to give values not differing much from those obtained on the eastern coast at Blue Hill.

Taking Mt. Washington and Thatcher's Island we have

Station.	Period of obs.	J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.	Year
Mt. Wash....	1881-87	43 6	42 8	38.7	31.6	29.7	30.2	28.7	28 5	31.8	32.1	35 6	39.2	33.7
Thatch. Id...	1876-83	17.2	17.8	17.2	14 1	12.2	10.4	9.5	9.1	11.7	13.1	16.0	16.8	13.8
Mt. Wash. ÷ Thatch. Id.		2.54	2.40	2.25	2.24	2.43	2.90	3.02	3.13	2.72	2.45	2.22	2.33	2.44
Mt. Wash. — Thatch. Id.		26.4	25.0	21.5	17.5	17.5	19.8	19.2	19.4	20.1	19.0	19 6	22.4	19.9
Increase m. p. h. per 100 meters.....		1.39	1.31	1.13	.92	.92	1 04	1.01	1.02	1.06	1 00	1 03	1.18	1.05
Increase m. p. h. per 100 ft.		.42	.40	.34	.28	.28	.32	.31	.31	.32	.30	.31	.36	0.33

If we take the mean between Thatcher's Island and Block Island (for B. I. the years 1881–86 have an average of 14.6) it would give for the sea stations 14.2 m. p. h. mean annual wind; and this would give 2.37, 19.5 and 1.03, instead of 2.44, 19.9 and 1.05, respectively, as found by using Thatcher's Island alone. In this comparison it is interesting to note the annual march of the increase with elevation; and it seems clearly to prove that

no short series of experiments can determine the law of increase of wind with elevation; for "monthly constants" will be required to reduce the means of observed velocities to any definite plane. The march of the absolute difference shows a maximum in January and a minimum in May: the ratio of this maximum to minimum is as 1.36 to 1.00. The ratios of Mt. Washington to Thatcher's Island show a maximum in August and a minimum in April.

In order to get the increase of wind with elevation above the *land*, Mt. Washington is compared with Portland and Burlington.

	J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.	Y.
Mt. Wash. 1881–87	43.6	42.8	38.7	31.6	29.7	30.2	28.7	28.5	31.8	32.1	35.6	39.2	33.7
Portland 1872–85	7.7	8.4	9.1	8.8	7.8	6.9	6.6	5.8	6.7	7.4	8.3	7.9	7.6
Burlington 1872–83	8.3	7.6	8.1	7.7	6.8	6.1	5.7	5.3	6.7	7.2	8.6	8.4	7.4
Mt. Wash. — Port	35.9	34.4	29.6	22.8	21.9	23.3	22.1	22.7	25.1	24.7	27.3	31.3	26.1
Mt. Wash. ÷ Port	5.7	5.1	4.3	3.6	3.8	4.4	4.3	4.9	4.7	4.3	4.3	5.0	4.4
Mt. Wash. — Burlington	35.3	35.2	30.6	23.9	22.9	24.1	23.0	23.2	25.1	24.9	27.0	30.8	26.3
Mt. Wash. ÷ Burlington	5.6	5.6	4.8	4.1	4.4	5.0	5.0	5.4	4.7	4.5	4.1	4.7	4.6
Average Port. and Burl	8.0	8.0	8.6	8.2	7.2	6.4	6.2	5.6	6.7	7.3	8.4	8.2	7.5
Increase m. p. h per 100 feet for $\frac{\text{Port.} + \text{Burl}}{2}$ & Mt W.	.58	.56	.49	.38	.36	.38	.36	.37	.40	.40	.44	.50	.42

For determining the increment of velocity from sea level to Blue Hill Summit we have no comparisons that can be used directly, as Thatcher's Island station was given up before the Blue Hill Observatory was established. While the irregularities in the monthly velocities at Blue Hill are considerable, yet the annual march can be approximately determined from the three years' observations (1885–86–87*) at my disposal. Therefore an attempt is made to get a result, although only a rough approximation can be obtained. Let us first compare the average results at Thatcher's Island with the Blue Hill average.

Period of obs.	J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.	Y.
Thatcher's Id. 1876–1882	17 2	17.8	17.2	14.1	12 2	10 4	9.5	9.1	11.7	13 1	16 0	16.8	13.8
Blue Hill 1885–87	21.0†	23 4	22.2	19 6	16.6	16.0	14.6	14.7	16.4	18.3	21 4	22.7	18 9
Blue Hill — Thatch. Id.	3 8	5.6	5.0	5.5	4.4	5.6	5.1	5.6	4.7	5.2	5.4	5.9	5.1
Blue Hill ÷ Thatch. Id.	1.22	1.32	1.29	1.39	1.36	1.54	1.54	1 62	1.40	1.40	1.34	1.35	1.37

Another way of comparison would be to compare the years 1885–87 at Blue Hill with the same years at Block Island after the results obtained at the latter place have been corrected by

* Communicated by Director A. L. Rotch to F. Waldo.

† (For 1886 and 1887 only).

applying monthly constants in order to reduce them to the location of Thatcher's Island; these constants to be determined by comparing the average monthly values obtained for about six years at Thatcher's Island and Block Island; the Block Island observations themselves ought hardly to be compared directly with those made at Blue Hill (for monthly comparison) on account of the difference in location. The comparison of the annual amount observed in 1885 and 1886 give:

	1885	1886
Block Island (less 5% to reduce to Thatcher's Island).....	13.3	13.6
Blue Hill	18.9	19.1
Difference, m. p. h.....	5.6	5.5

From this we find an increase of .92 m. p. h. per hundred feet of elevation. From Thatcher's Island we found .85 m. p. h., so that we may take about .90 m. p. h. as the annual increase of velocity for each 100 feet (3.0 per 100 meters) from sea level up to 600 feet above land, for the regions near Boston. Expressed in percentage of the wind velocity observed near the water surface in coast waters, the increase with velocity is about 7 per cent. for each 100 feet (22 per cent. per 100 meters) while for Thatcher's Island and Mt. Washington we got 2.4 per cent. for each 100 feet (or 7.6 per cent for each 100 meters).

If we consider Block Island as representing more nearly the open ocean, and Thatcher's Island the coast waters merely, then the increase with elevation above the open ocean would be nearly 0.85 mile per hour per hundred feet elevation.

In the ratios Blue Hill to Thatcher's Island, the maximum is in midsummer and the minimum in midwinter; while the ratios for the greater differences in elevation above the land as Mt. Washington to Portland, the maximum is in midwinter and the minimum in early summer. In the ratios Mt. Washington to Thatcher's Island, the maximum is in midsummer (as for Blue Hill to Thatcher's Island), and the minimum in April with a secondary maximum in January and minimum in November.

From the Mississippi River westward there is a long gradual slope upwards, termininating at the base of the Rocky Mountains. There is here a gradual increase of wind velocity with

elevation up to a certain height and it is of interest to investigate the law of this increase.

St. Louis, Cairo and Keokuk, in the Mississippi valley, Leavenworth, Omaha and Yankton, the places where the ascent of the slope has fairly begun, and Ft. Elliott, Dodge City and North Platte, the middle of the slope, but the point of apparent maximum of wind velocity. The mean annual velocities are used.

		Elev. Bar. meters.	Elev. Anem. meters.	Velocities. m. p. h.
	St. Louis	174	63.4	9.8
	Springfield*	196	28.0	8.7
I.	Cairo	109	25.0	7.3
	Keokuk	187	22.3	8.0
	Mean	164	25.1	8.0
	Leavenworth	256	20.1	7.1
II.	Omaha	337	27.4	8.9
	Yankton	371	12.8	9.1
	Mean	321	20.1	8.4
	Dodge City	771	16.7	12 3
III.	Ft. Elliot	823	7.3	11.3
	North Platte	866	13.4	11.4
	Mean	820	12.5	11.7

Mean.	Elevation Bar. meters.	Elevation Anem. meters.	Velocities. m. p. h.
I	164	25.1	8.0
II	321	20.1	8.4
III	820	12.5	11.7

That is, from elevation (above sea level) 164 meters to 321 m. the increase is .27 m. p. h. or 2 per cent. for each 100 m. of elevation.

From 321 m. to 804 m. the increase is .66 m. p. h. or 8 per cent. for each 100 m. (counting from the lower station.)

We have also for Pike's Peak and III (mean):

	Elev. Bar. meters.	Elev. Anem. meters.	Velocities. m. p. h.
Pike's Peak	4308	4.5	20.1
III (mean)	820	12.5	11 7

This gives from 820 m. to 4308 m. an increase of .24 m. p. h. for each 100 meters.

Pike's Peak being the highest station in the world, it is of

*(Substituted for St. Louis.)

importance to compare the monthly means of wind with those of neighboring and lower stations; but there is great difficulty in selecting the proper comparison station.

Dodge City certainly furnishes good data for a freely exposed station at a moderate elevation; but the low velocities at Denver lead one to think that the mountains must protect it from the winds; Cheyenne however seems to be more freely exposed, and offers perhaps a good opportunity for comparison of that elevation with Pike's Peak.

It will be of interest however to compare these stations, even if the results are not to be depended on with much certainty.

	J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.	Y.
Pike's P'k, m p h.	25.0	25.3	25.3	21.3	21.5	19.0	12.7	12.0	16.1	21.1	19.7	22.0	20.1
Cheyenne..... ..	12.9	12.4	12.5	11.8	10.5	9.2	8.9	8.1	8.9	10.0	11.0	11.2	10.6
Denver.....	6.4	6.2	7.3	7.3	6.8	6.4	6.1	5.6	5.6	5.9	6.1	5.9	6.3
Dodge City.....	10.9	11.5	14.0	14.9	14.5	13.3	12.6	11.1	12.4	12.0	10.4	10.3	12.3
Pik's P'k — Chey.	12.1	12.9	12.8	9.5	11.0	9.8	3.8	3.9	7.2	11.1	8.7	10.8	9.5
Pik's P'k — Denv.	18.6	19.1	18.0	14.0	14.7	12.6	6.6	6.4	10.5	15.2	13.6	16.1	13.8
Pik's P'k — Dg.C.	14.1	13.8	11.3	6.4	7.0	5.7	0.1	0.9	3.7	9.1	9.3	11.7	7.8

These differences show an annual march with a February maximum for Cheyenne and Denver as comparison stations, and a January maximum for Dodge City. The minimum for all occurs in July and August. A secondary maximum in October is also found for the first two differences. This difference shows a marked contrast with those obtained by comparing Mt. Washington with lower stations. The most remarkable fact is that in August the velocities at Pike's Peak and Dodge City are about equal; but this comes out more clearly in the following table of ratios:

	J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.	Y.
a Pike's P'k. ÷ Chey.	1.94	2.04	2.02	1.81	2.05	2.06	1.43	1.48	1.81	2.11	1.79	1.97	1.90
b Pike's P'k. ÷ Denv.	3.91	4.08	3.47	2.92	3.16	2.97	2.08	2.14	2.88	3.58	3.23	3.73	3.1$_9$
c Pike's P'k. ÷ Dg C.	2.29	2.20	1.81	1.43	1.48	1.44	1.01	1.08	1.30	1.76	1.89	2.14	1.63

In this table we find considerable irregularity in the annual march: for *a* there are maxima occurring in February, June, October, and minima in April, July and November; for *b* there is a maximum in February, May, October, and minimum in April, August, November; for *c* there is a maximum in January, and a minimum in July.

The close agreement of the phases for *a* and *b* lead to the inference that the winds at the elevations of Cheyenne and Denver are of the same *character* and that the difference in

amount is in some way connected with the exposure either of the place of observation or of the anemometer. Not being personally familiar with the locality I am unable to enter further into the question as to which of these is to be considered as representing the wind at that elevation.

SECTION VII. INCREASE OF SURFACE WIND VELOCITIES WITH LATITUDE.

If we compare the stations of the Mississippi Valley and corresponding stations north, commencing at Vicksburg (as New Orleans is too near the Gulf coast and the Lake) we obtain the following table:

	Station.	Elev. above Sea Level. Met.	Elev. of Anem. Met.	Velocity. m. p. h.
I.	Vicksburg	67	20.7	5.4
	Memphis	97	23.4	5.4
	Cairo	109	25.0	7.3
II.	St. Louis	174	63.4	9.8 [8.0]
	Keokuk	188	22.3	8.0
	Davenport	187	25.9	8.4
	*Dubuque	202	18.9	5.3
	Lacrosse	221	23.4	7.4
III.	St. Paul	253	37.8	8.3
	Moorhead	281	17.9	10.8
	St. Vincent	245	7.3	9.0
I.	(average)	91	23.3	6.03
II.	"	192	23.9	7.93
III.	"	260	21.0	9.37

Comparing these three groups, we find that from 90 to 190 met. altitude and changing from $\phi = 35°$ to $\phi = 41°$ the increase is 1.87 mile for each 100 met, while for the altitudes from 190 to 260 and changing from $\phi = 41°$ to $\phi = 47°$ the increase is 2.12 miles for each 100 meters.

How much of this increase is due to the increase in latitude,†

* Omit in the discussion.

† Taking stations between Atlantic ocean and 100° meredian, but not using the exposed sea coast and lake stations, the following approximate table is obtained (irrespective of altitude):

ϕ	30°—35	35°—40	40°—45°	45°—50
No. stations used	12	18	15	3
Average ann. velocities	6.5	6.4	7.9	9.6

which would seem to indicate an increase of velocity with ϕ.

which would seem to indicate an increase of velocity with ϕ, and the consequent nearer approach to the path of greatest frequency of "Lows," and how much to difference in altitude it is difficult to determine. The question of open "Prairie Lands" in the north and "Bottom Lands" in the south also comes in. We might compare these velocities with those observed on the ocean, but I have not enough material at hand to make the work thorough. However, a comparison with the Atlantic Ocean data for the years 1881, 1882 (C. S. O. Ann. Rep. 1883–1884), may indicate some relations.

ϕ =	22.5°	27.5°	32.5°	37.5°	42.5°	47.5°	52.5°	57.5°	Year.
Vel. 0–10	2.8	2.9	2.8	3.2	3.5	4.05	3.9	3.6	1881
	1.8	1.9	2.1	2.7	3.1	3.7	3.7	3.2	1882
Velocity miles per hour	10.4	10.8	10.4	12.7	14.5	18.3	17.2	15.2	1881
	5.8	6.3	7.3	10.0	11.9	15.8	15.8	12.7	1882
Mean m. p. h.	8.1	8.6	8.8	11.1	13.2	17.0	16.5	14.0	

The reduction from the scale 0–10 to miles per hour is made *directly* by means of Abbe's table plotted (see the reduction of the Cambridge observations), and is a little different from the conversion given in my paper in *Met. Zeits.*, 1888, p.—,when the reduction curve was necessarily smoothed out, as fewer points were given.

While there is considerable difference in the wind for the two years, yet each shows a maximum at about 50° latitude, which is nearly in the path of greatest frequency of "Lows." For the mean of the two years there is a slow increase from 22° to 32°, and a rapid increase from there to about 50°, with an apparent decrease north of this line. It is probable that a similar tendency to increase with φ up to certain limits is felt in the United States, but is much modified by the land.

SECTION VIII. GRAPHICAL REPRESENTATION OF DISTRIBUTION OF WIND VELOCITIES IN UNITED STATES.

The ratios max. : min. given in col. 5 of Table I were charted as a map of the U. S., and an attempt was made to draw continuous lines connecting the equal ratios. For the main region east of the Rocky Mountains fairly accordant results were obtained. The line passing through the points having the ratio

1.6, which being about the average value, I have assumed as the dividing line between the regions having extreme values, may be located by the following points: New Orleans, Charlotte, N. C., Philadelphia, New York, New Haven, Boston, Portland, Burlington, Toronto, Cleveland, (just north of) Indianapolis, Davenport, Dubuque, Yankton, Fort Sill, Palestine, Galveston. Within the limits just stated, the ratios are all over 1.6; but there does not seem to be any law of distribution, although the 1.7 line follows pretty closely the contour of the 1.6 line (with exceptions): Outside of the 1.6 line on the north we find the 1.4 line connecting Ft. Benton, St. Vincent, St. Paul, La Crosse, Escanaba, Mackinaw and Alpena. One peculiarity of the Lake Region being that for all of the Lake stations west of Sandusky the ratios are under 1.6 (being within exception 1.4 or 1.5), while for those east of Sandusky they are all more than 1.6 (nearly all being 1.8).

On the south and east of the 1.6 line, the 1.4 line connects Mobile, Cedar Keys, Jacksonville, (near) Savannah, and passes along near the coast to Norfolk; a minimum of 1.2 being found at Charleston, and 1.3 on the Carolina coast. North of Norfolk the values for the coast stations are somewhat irregular.

Fragmentary lines were also drawn for the Southwestern and Western portions of the U. S., but they were unsatisfactory. It has not been considered necessary to reproduce this chart.

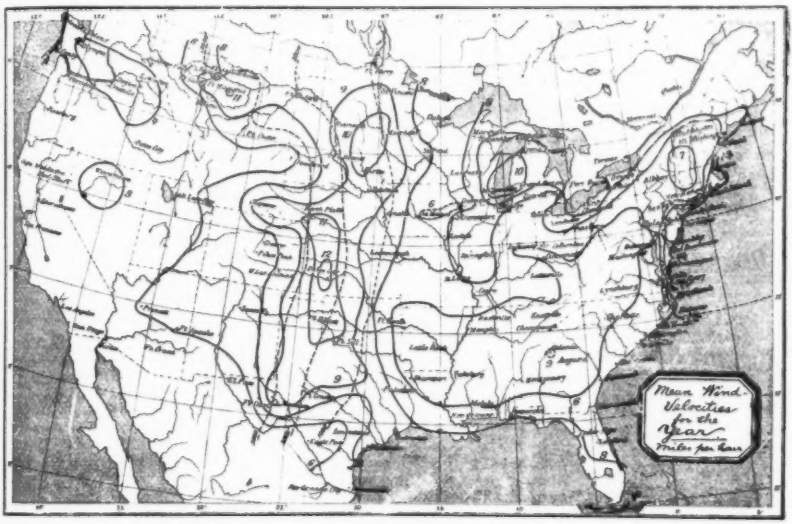
The accompanying charts giving the average wind velocities for the Year, January and July, show with tolerable accuracy the wind distribution east of the Rocky Mountains. West of this range, however, the lines drawn are largely hypothetical, as the country is so cut up by mountain ranges; still, even there, the lines probably have general significance. A glance at these charts shows the following points:

Annual Chart.—A maximum occurs in Kansas at almost the centre of the United States. The lines of equal velocities around this maximum have a greatest length north and south, while from the Mississippi valley eastward the Isanemonals* principally extend east and west. This change of direction of

* I think the word "Isanemonen" was first used by Dr. Köppen.

the Isanemonals seems to occur with about the same stations at which the maximum changes from March to April.

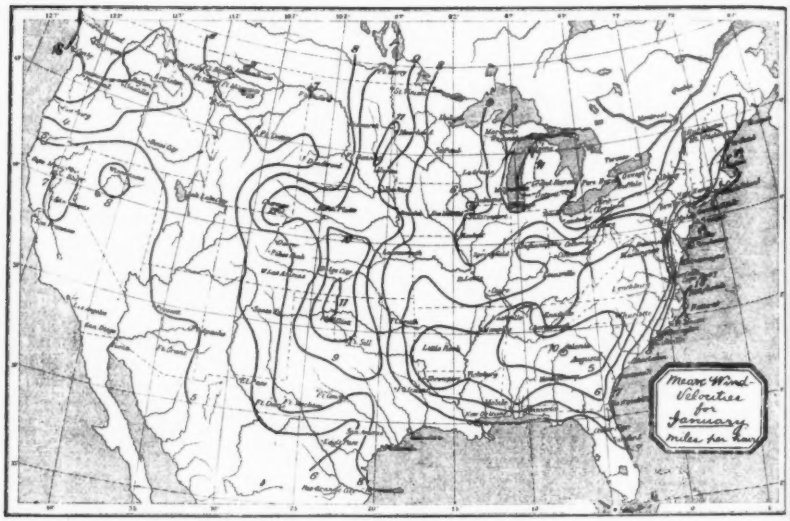
In the states east of the Mississippi river a maximum occurs in the lake region, due in part to closeness to the principal path of "Lows," and partly to exposure of anemometers to the lake winds. In central New England there is a slight minimum; and low velocities are observed inland in the states south of the Ohio river. The maximum at Atlanta is probably caused by

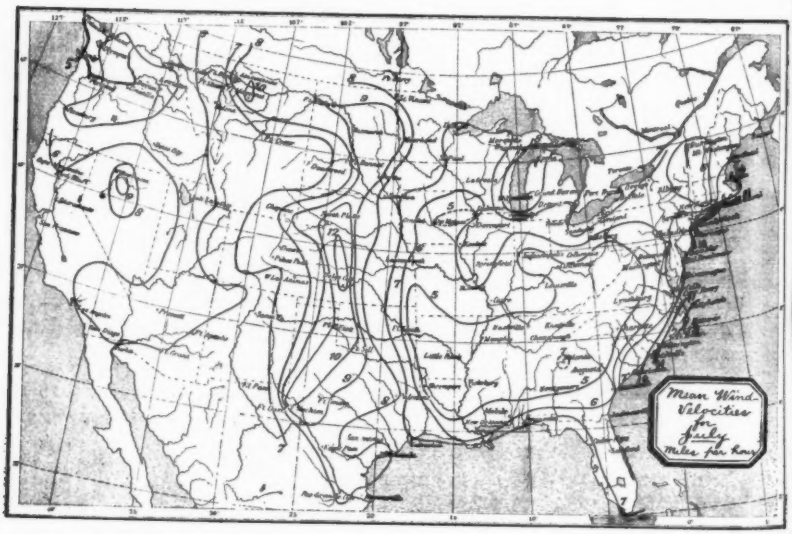


the very high exposure of the anemometer as well as the location of Atlanta on a high plateau. The minimum at Des Moines and Dubuque is also probably due to local influences.

On this chart, on the slope west of the Mississippi river, were drawn dotted lines showing the approximate location of the contours of elevation for 1,000, 2,000 and 3,000 feet above the sea, and the Isanemonals for this region are in general nearly parallel to them. The effect of the Rocky Mountain range seems to make itself felt on the winds to a distance of 200 or 300 miles to the eastward.

The great plateau to the west of the Rocky Mountains has


Mean Wind-Velocities for January
Miles per Hour


Mean Wind-Velocities for July
Miles per Hour

about the same amount of wind as the Ohio valley. In the extreme northwest the low wind velocities are due to the numerous cross mountain ranges. The velocities in the southwest are small.

The January chart presents pretty much the same characteristics as the annual chart, and need not be further described. The July chart shows the following peculiarities: The velocity gradients in the region of the Kansas maximum are considerably steeper for this season; the excess of wind at Atlanta over the neighboring stations is not nearly so marked, and the velocity gradient from the lake region southward is somewhat less steep. The remarkably low velocities on the extreme northwest coast are also worthy of attention.

The fact that Isanemonals can be drawn with the general symmetry represented on these charts, goes far to show that there is probably uniformity in the exposures of anemometers for *like* regions, to within limits of 10 to 15 per cent. This does not guarantee, however, that the velocities are comparable for the different parts of the country. The exposed sea coast, the large cities, the smaller cities, frontier towns, forts, etc., all offer characteristic exposures, and before accurate Isanemonals can be drawn from the present data, reduction factors to a common standard will have to be obtained experimentally, and in this connection the following remarks are offered on this subject in general:

The reduction of ocean observations of wind to a common level is not necessary, as most of the estimations are made from the ship's deck and the few feet difference in elevation for larger vessels would only cause differences far within the limits of error of observation. Not so with the land, however, and to the question of a common plane of reduction considerable study has been given, but without much success. One naturally asks, is the question one that can be decided, or, from its nature, is it useless to consider it.

I think that a method can be arranged that will allow of an accuracy within, say, 10 per cent. of the whole wind amount for average values; but a great deal of time and study will be re-

quired on the part of the investigator and much experimental work would have to be done. In Europe and America there are two different conditions existing for wind observations, and they would require different methods of reduction. In Europe most of the observations are estimations on some arbitrary scale of wind velocities which would have to be reduced to some common standard before they could be considered as a whole. Besides this, there are scattered observatories where anemometers are mounted, and the results obtained for these latter would greatly assist in the absolute reduction of all observations to a common system. By means of these two systems combined there has undoubtedly been published material enough for a good comparison of the wind velocities for various parts of Europe, and for drawing Isanemonals for most of the continent*; but the labor of getting this material into proper shape would be very great. In the United States the tabulated Signal Service observations do not require the great amount of preliminary work that would be necessary for Europe, and for the period up to 1885 the consideration of the question of reduction to a common plane can be entered upon almost directly by any one having access to the necessary data.

A mention of some of the points that have suggested themselves to me while thinking about this subject may be of use. The question of what shall be the plane of reference, or of reduction, one can hardly foretell, for there are several planes that can, perhaps, be used. What is wanted is a common reduction plane to which the observations can be reduced so that we can compare the winds of different regions; for instance those of the Ohio Valley with those of the Atlantic sea coast. Such a reduction plane is necessary that, when we have given the average wind velocity of any place referred to this plane, we can at once tell the probable amount of wind for any desired point in the locality, whether it be in a valley, on a plain, on a hill, in a city or in the country.

I have made no attempt to reduce the present data to a common plane because the necessary information is lacking, for,

* See Kiersnowsky's paper received since this was written.

before the different observing stations can be united into any system, we must have an accurate orientation from the place of observation and the location of influencing surroundings carefully noted. A good way of recording this for each station would be to prepare diagrams, which can be described as follows: Locate a point on the centre of a sheet of paper, as the observing station. With this point as a centre describe successive circles, each one having a radius half an inch greater than the preceding. Locate the eight points of the compass on the outer limits of the diagram and call the first circle lying at the centre 100 feet, the 2nd 500 feet, the 3d ¼ mile, 4th, 1 mile, 5th, 5 miles, 6th, 10 miles, from the centre. With the aid of a hand spirit level estimate the height above or below the level of the anemometer, of various points between these circles along the lines drawn from the station to the eight points of compass. Both horizontal and vertical distances can be estimated with sufficient accuracy. Distances above the anemometer level are + and those below are —. Of course only the vertical elevations or depressions need be entered in figures on the sketch, as the horizontal distances will be shown by the diagram. Should any large obstructions come between the points of compass given within the first two circles it must be noted on the sketch with the proper elevation or depression referred to the observer's horizon. Also, if any mountains are within influencing distance, the position, distance and elevation should be noted. By means of such maps, the person who works up the collected data can judge pretty well in which class he shall place the observations from each station.

Reduction to plane of sea level. It would obviously be most convenient for comparative purposes to adopt a level of, say 25 feet, above the sea as a plane of reference, because then all ship observations would need no reduction, and the reduction factors for land observations need only be sought for different locations.

Reduction to the plane above the earth's surface where the friction constant ceases to change rapidly, or to the plane where the wind velocities over the land are no different from those over the sea. In the case of the Thatcher Island, Boston, and

Blue Hill observations, it is readily seen that there is a plane, perhaps not more than 300 feet above the earth's surface, where the two lines of increase of velocity will practically unite. If such a plane is used, then the increase of velocity with height above the sea and land must be determined for various parts of the globe.

Reference to some chosen plane, for instance about 25 feet above surrounding level of ground or roofs, so that most of the anemometers can be so placed as to require no reduction to the plane. Of course in this case the land and water observations could not be combined, and great care would have to be observed in placing the anemometer in a normal exposure.

[CONCLUDED.]

ERRATA:

Page 220, last line, for Santio read Santis.
Page 225, footnote, for Marion read Marvin.
Page 257, fifth line from bottom, after minimum place an *.
Page 261, for curve XIX the star in col. Y should be on line five.
Page 304, 14 lines from bottom, for Beld read Bild.
Page 308, transpose "by Laplace's formula" from 8 line from top to after the word "However"in line 11.

CORRESPONDENCE.

THERMOMETER ERRORS.*

MY DEAR PROFESSOR:— * * * * I am now making an investigation of five thermometers of special forms made for me by Green. I have nearly completed the work on two of them. By the way, I doubt if I have made any real discovery. I have probably made it clear that the discordances which exist between different observers are due to the periodic error in estimating the fractions of a division of the scale to error of personality. In my own case these corrections are well defined and very constant. After these errors are taken out, the errors which remain appear to be periodic, but whether the pulsations have a

* This is a part of a private letter to one of the editors, to the publication of which Professor Rogers kindly gave his consent. It relates to the very interesting periodic errors of the thermometer studied by Prof. Rogers and Mr. Woodward. Many of our readers will probably wish to try for Prof. Rogers the observation mentioned. H.

recurrence under a definite law, as Woodward in his beautiful investigations has shown, I am not yet quite sure. In fact, I am still groping about in the dark. The result so far reached is that I can account for about one-half of the systematic errors, and the other half I am not sure about.

According to present indications, the periodic recurrence of the pulsations is limited to observations made under air contact and not in liquid contact.

There is one observation, which is easily made, which puzzles me greatly; and in this the mercurial column seems to have its progress delayed in passing a graduation mark. I wish you would try the experiment. Count half seconds as you note the rise of a column, first for the time of occultation, and then note for the same time the position of column. To me it has passed beyond the mark a distance about twice as great as the width of the mark.

Naturally one would class this apparent change of rate of progress of the column as a subjective observation, but it seems to me real. The width of the lines in my standard is about one-seventh of the one-fifth degree space; but to pass over the line takes about two-sevenths of the time required to pass over the one-fifth degree space.

I am anxious to get the experience of others on this point. The observation will take but little time. I prefer a rise of about one degree in twenty minutes. Faithfully yours,

W. A. ROGERS.

WATERVILLE, MAINE, November 18, 1889.

CURRENT NOTES.

ATLAS OF CLOUDS.—The observation of the clouds, being the chief evidence of the state of, and the occurrences in, the free atmosphere, has increased in importance during the last years with regard to meteorology. The direction of the wind, the velocity and the height of the various cloudforms are becoming more and more a subject of investigation for scientists of all countries. Should these investigations be compared with

each other it becomes necessary that they should agree in the use of the same expressions for the same ideas. One of the greatest obstacles, however, lies in the difficulty of producing good representations of clouds. Photography has achieved much that is good with regard to the production of detail in the cloudforms, but at the same time it has been quite insufficient in as far as the general character of the aspect of the sky is concerned; it is especially insufficient to give a right view of the subject to those who have not studied it beforehand. Regarding other one-colored representations of clouds the case is still worse.

The undersigned publishers have therefore upon the advice of well-known meteorologists decided to publish chromo-pictures of the most important cloud-forms. The collection has been commenced by Professor H. H. Hildebrandsson of Upsala, and the selection has likewise been made by him in connection with the director of the Marine Observatory, Prof. Neumayer of Hamburg and Prof. Koeppen of the same town, from a large number of cloud-pictures, painted in oil for the purpose, by various painters of Sweden and Germany. Part of the pictures have been improved under the guidance of the gentlemen just mentioned and the greatest care has been taken to obtain the most characteristic representations. The classification made use of is that by Hildebrandsson and Abercromby. In the execution of the pictures the kind advice of Mr. Weilbach of Copenhagen has been accepted.

The great expense of the publication of these cloud-pictures has been somewhat reduced by the assistance of the Legacy of "Lars Hiertas Minne" of Stockholm through which it will be possible to sell the collection of twelve pictures, the size of 9x12 inches (without the margin) with short printed explanations in German, English and French, and map, for the price of $3.00 a copy, (by ordering twenty-five copies, each copy $2.50,) in case that a sufficient number of meteorological institutes will subscribe, as has been already promised by several of them.

Subscriptions should be sent to Besthorn Brothers, successors to Gustav W. Seitz, Hamburg, Germany.

NORTHERN PACIFIC RAILROAD

LANDS FOR SALE.

The Northern Pacific Railroad Company has a large quantity of very productive and desirable **AGRICULTURAL AND GRAZING LANDS** for sale at LOW RATES and on EASY TERMS. These lands are located along the line in the States and Territories traversed by the Northern Pacific Railroad as follows:

In Minnesota,	-	Upwards of 1,350,000 Acres
In North Dakota,	-	" 7,000,000 Acres
In Montana,	-	" 19,000,000 Acres
In Northern Idaho,	-	" 1,750,000 Acres
In Washington and Oregon,	-	" 12,000,000 Acres

AGGREGATING OVER 40,000,000 ACRES.

These lands are for sale at the LOWEST PRICES ever offered by any railroad company, ranging chiefly

FROM $1.25 TO $6.00 PER ACRE, AND ON 5 AND 10 YEARS' TIME,

For the best Wheat Lands, the best diversified Farming Lands, and the best Grazing Lands now open for settlement.

In addition to the millions of acres of low priced lands for sale by the Northern Pacific R. R. Co., on easy terms, there is an equal amount of Government lands lying in alternate sections with the railroad lands, open for entry, free to settlers, under the Homestead, Pre-emption and Tree Culture laws.

DO THIS!

WRITE FOR PUBLICATIONS RELATING TO MINNESOTA, NORTH DAKOTA, MONTANA, NORTHERN IDAHO, WASHINGTON AND OREGON

An attractive belt of country reaching from Lake Superior to the Pacific Ocean and Puget Sound, and noted for its rich natural resources.

The Northern Pacific Railroad Company mail free to all applicants the following **Illustrated Publications, containing valuable maps,** and describing Minnesota, North Dakota, Montana, Idaho, Washington, and Oregon, viz.:

A **SECTIONAL LAND MAP OF NORTH DAKOTA,** showing the Government lands open to settlers, and those taken up, and the railroad lands for sale, and those sold in the district covered by the map.

A **SECTIONAL LAND MAP OF EASTERN WASHINGTON AND NORTHERN IDAHO,** showing the unoccupied and occupied Government lands, the sold and unsold railroad lands, with descriptive matter relating to this portion of the Northern Pacific country.

A **SECTIONAL LAND MAP OF WESTERN AND CENTRAL WASHINGTON,** showing the unoccupied and occupied Government lands, the sold and unsold railroad lands, in Central and Western Washington, including the Puget Sound section, with descriptive matter concerning the extensive timber regions, mineral districts, and the **agricultural and grazing lands.**

A **MONTANA MAP,** showing the Land Grant of the Northern Pacific R. R. Co., and the Government surveys in the district covered by the map, with descriptions of the country, its grazing ranges, mineral districts, forests, and agricultural sections.

ALSO SECTIONAL LAND MAPS OF DISTRICTS IN MINNESOTA.

When writing for publications, include the names and addresses of acquaintances, and publications will be sent to them also.

SUPERB TRAIN SERVICE.

The Northern Pacific passenger trains are equipped with Pullman palace sleeping cars, colonist sleeping cars, dining cars, and first-class coaches. The colonist sleeping cars are run on the daily fast through express trains, without extra charge for berths.

For full information relative to rates, tickets, sleeping and dining cars, and for copies of illustrated publications including the "Wonderland" and "Alice Folder," describing the summer resorts, Yellowstone National Park, California, Alaska, etc., with maps of the Park and line of road, apply to or address

CHAS. S. FEE, Gen'l Pass. and Ticket Ag't, St. Paul, Minn.

☞ WRITE FOR PUBLICATIONS. ☜

They are illustrated, and contain valuable maps and descriptive matter, and are MAILED FREE OF CHARGE to all applicants. For information relating to lands and the Northern Pacific country, address

P. B. GROAT, GENERAL EMIGRATION AGENT, OR **CHAS. B. LAMBORN,** LAND COMMISSIONER,

ST. PAUL, MINNESOTA.

AMERICAN METEOROLOGICAL JOURNAL.

AN ILLUSTRATED MONTHLY

DEVOTED TO SCIENTIFIC METEOROLOGY AND ALLIED BRANCHES OF STUDY.

THE AMERICAN METEOROLOGICAL JOURNAL CO., Publishers and Proprietors,
Ann Arbor, Michigan.

M. W. HARRINGTON,
Director of the Astronomical Observatory, Ann Arbor, Michigan,
A. LAWRENCE ROTCH,
Proprietor of the Blue Hill Meteorological Observatory, Massachusetts,
W. J. HERDMAN, PH. B., M. D.,
University of Michigan.
Editors.

KITTREDGE & MORAN, Managers.

PRICE,—IN THE UNITED STATES, - - - - $2.00 per year
" IN COUNTRIES OF THE POSTAL UNION, - - 2.25 " "

The editors solicit communications on all subjects having any bearing on Meteorology, or Climatology. Correspondence on events of current interest is invited, and accounts of local newspapers concerning them will be welcome. Notes on local climate will be published and the columns of the JOURNAL are freely open for worthy communications on all matters within its scope. The editors do not hold themselves responsible for any communications which may be signed or attributed to other authorship than their own.

Contributors will be furnished free with five copies of the issue in which their articles appear. Additional copies can be furnished them at the rate of 12 for $2.00. Reprints will be furnished, with cover and title, at the rate of $6.00 per hundred for anything less than one form (16 pages); $12.00 between one and two forms; and $6.00 for each additional form or fraction. The order for reprints must accompany the copy.

Communications relating to the contents of the JOURNAL may be sent to either editor. Subscriptions and all other letters relating to business matters, should be sent to the

AMERICAN METEOROLOGICAL JOURNAL CO.,
Ann Arbor, Mich.

JUST OUT!

RESEARCHES IN ELECTRO-ALLOTROPIC PHYSIOLOGY

Containing much scientific information and many valuable abstracts on Electro-Therapeutics. This handsome 115 pp. pamphlet will be mailed for only 24 cents in stamps to those who mention "THE AMERICAN METEOROLOGICAL JOURNAL." Address,

JEROME KIDDER M'F'G CO., 820 Broadway New York, N. Y.

Chicago, Milwaukee & St. Paul R'y.

Steam Heated and Electric Lighted Vestibuled Trains to St. Paul and Minneapolis.

Finest Dining Cars in the World.

Through Sleeping Cars to Denver.

The Route of the first "Golden Gate Special."

Excursion Tickets to Colorado.

Excursion Tickets to California.

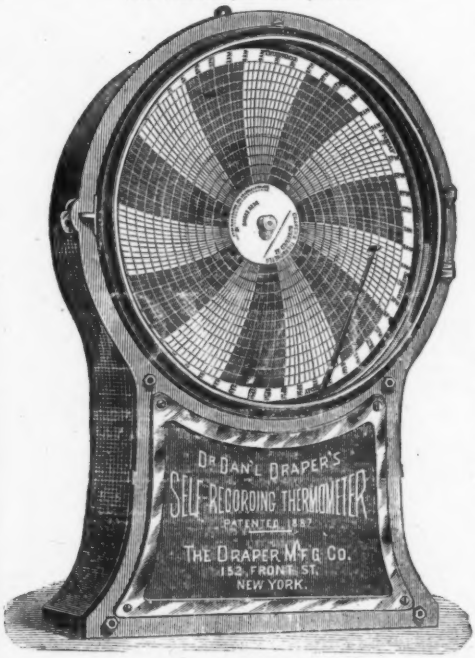
Everything First-Class.

First-Class People patronize First-Class Lines.

Ticket Agents everywhere sell Tickets over the Chicago, Milwaukee & St. Paul Railway.

DRAPER'S SELF-RECORDING THERMOMETER.

DESCRIPTION OF THE INSTRUMENT
AND DIRECTIONS FOR ITS USE.



SIZE 14 BY 20 INCHES.
Protected by Letters Patent in the United States, Canada, Great Britain, France, Germany, Austria, Hungary and Belgium.

STANDARDIZED AND WARRANTED.

MANUFACTURED BY THE
DRAPER MANUFACTURING COMPANY,
152 FRONT STREET, NEW YORK CITY.

This thermometer gives a permanent and continuous record in ink of the temperature. The chart indicating hours of the day and days of the week, gives the degrees of temperature from 20° below zero to 110° above. All instruments are accurately adjusted and warranted. The record is easily read and absolutely correct. Sold by the leading instrument dealers and opticians throughout the United States and Canada, and by

The DRAPER
MANUFACTURING CO.,

Owners of the United States and foreign patents, 152 Front Street, New York.

COLORADO COLLEGE,
COLORADO SPRINGS, COLORADO.

THE CLASSICAL, LITERARY AND SCIENTIFIC DEPARTMENTS are now strongly equipped.
Special Winter Courses are given in Assaying and Determinative Mineralogy.
Students unable to continue their work in the East on account of Pulmonary diseases or Malaria, in this climate can pursue their studies uninterruptedly, and often regain their health at the same time.
For further information Address President SLOCOM.

ROSE POLYTECHNIC INSTITUTE, TERRE HAUTE, IND.
A SCHOOL OF ENGINEERING.
Well endowed, well equipped departments of Mechanical and Civil Engineering. Electricity Chemistry, Drawing. Extensive Shops and Laboratories. Expenses low. For catalogue address T. C. Mendenhall, Pres.

EXCHANGE OF BOOKS.

Any one who has **Books of Travel**, or **Mathematics**, or odd, early volumes of **Harpers'**, **Scribner's**, or **St. Nicholas** which they wish to exchange for **Novels** or books on **Natural History** can perhaps effect the exchange by addressing **Lock-box 3034, Ann Arbor, Mich.**

STANDARD THERMOMETER.

LEGIBLE.

5 inch Dial.

$2.50.

ACCURATE.

8 inch Dial.

$2.50.

(Metallic.)

Special Thermometers for Meteorologists with or without Telemeter attachments.

AGENTS:

THE FAIRBANKS SCALE HOUSES

In the principal cities of the United States.

COMPTOMETER

SPECIALLY ADAPTED TO ALL

METEOROLOGICAL COMPUTATIONS.

Addition

Subtraction

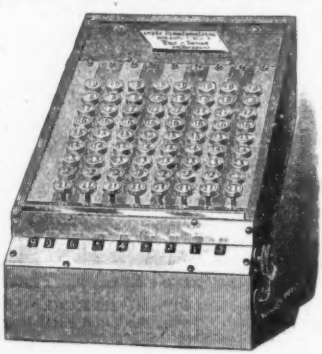
Multiplication

Division

Square Root

Cube Root

Common Fractions



Operated Entirely by Keys.

Saves 40 per cent of time.

Entire Relief from Mental Strain.

Adapted to all Scientific and Commercial Computations.

ALL Arithmetical Calculations can be solved Rapidly and Accurately by its use. . . . . Send for Circular.

FELT & TARRANT MFG. CO.,

52-56 ILLINOIS STREET, - - CHICAGO, ILL.